THE
UNIVERSITY
OF UTAH

August 19, 1994

Mr. Thomas P. Stanley
Chief Engineer
Federal Communications Commission
Washington, D.C. 20554

Re: "The matter of Guidelines for Evaluating the Environmental Effects of Radiofrequency
Radiation," E. T. Docket No. 93-62

Dear Mr. Stanley:

Kindly refer to my letter dated October 22, 1993 on the above subject. This letter is
being written to correct some of the numbers given in appendix B that was enclosed with
that letter. The overall conclusions of appendix B relative to the ten cellular telephones
examined remain the same in that the peak 1-g SARs are considerably smaller than the 1.6
W/kg suggested in the ANSI/IEEE C95.1-1992 safety guidelines. However, the numbers
pertaining to the specific absorption rates (SARs) have been revised upward to peak 1-g
SARs on the order of 0.26 to 0.69 W/kg. A revised version of the previously submitted
appendix B marked appendix B (revised) is enclosed herewith for your perusal.

This upward revision of SARs was necessitated by a mistake that we detected in
calculating the power being fed to the antenna for an initially assumed driving point voltage
(V_a) of the antenna for SAR calculations using the finite-difference time-domain (FDTD)
code. From the FDTD code we could calculate the antenna current I_a and the antenna
impedance $Z_a = V_a/I_a$ all of which was done correctly and in general agreement with
expected values for the various antennas. At this stage the power input (P_i) to the antenna
should have been calculated from the relationship

$$P_i = I\,I^* \, \text{Re} \, (Z_a) \qquad (1)$$

Instead it was calculated from the relationship

$$P_i = \frac{V_a V_a^*}{R_a} = \frac{V\,V^*}{\text{Re}(Z_a)} \qquad (2)$$

Equations 2 and 1 are identical when the antenna is purely resistive, i.e., the reactance X_a
of the antenna is zero. Otherwise, Eq. 2, which is incorrect overestimates the power input

to the antenna by a factor $\left(R_a^2 + X_a^2\right)/R_a^2$. Having thus overestimated the power into the
antennas for the various telephones we reduced the SARs to the scaled maximum possible

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antenna power of 0.6 W. This resulted in SARs that were lower everywhere by a factor $R_a^2/(R_a^2 + X_a^2)$ [1.08 to 2.47 for the various telephones].

It is unfortunate that the mistake also occurred for the experimental data. For experimental measurements, all of the telephones were placed against the right side of the model. Yet numerical calculations for most of the telephones (6 out of 10) were done for the telephone against the left side of the head, which because of proximity to the head, resulted in somewhat larger 1-g SARs. It is also likely that the telephones were not placed in a manner identical to that used for numerical calculations. For more recent experiments we have determined the range of peak local SARs that can result for somewhat different positions of the telephones vis a` vis the head. The new experimental values of peak SARs (in the ear) are in general agreement with the FDTD-calculated values.

Sincerely,

OM P. GANDHI
Professor and Chairman

OPG:cjp

Om P. Gandhi   8/19/94

ELECTROMAGNETIC ABSORPTION IN THE HUMAN HEAD
FOR CELLULAR TELEPHONES

We have used both computational and experimental techniques to obtain mass-normalized rates of electromagnetic energy absorption (specific absorption rates or SARs) in the human head for ten cellular telephones from four different manufacturers. For numerical computations we have used a newly developed high-resolution model of the human body that was obtained from the magnetic resonance imaging (MRI) scans of a male volunteer. For this model, anatomically based tissue properties were prescribed for each of the subvolumes or "cells" of dimensions approximately $2 \times 2 \times 3$ mm or 11.7 milligrams of the tissues. The well-established finite-difference time-domain computational technique was used to calculate the electromagnetic fields and SARs for all the regions of the body with particular emphasis on head, neck, shoulders, and the upper torso for cellular phones held against the ears. Because of the proximity of the upper ear to the radiating antenna, most of the electromagnetic absorption occurs for the upper cartilage-dominated part of the ear with a rapidly diminishing SAR for the nearby tissues in the head. For the tissues in the head, the SARs diminish rapidly to 1 percent of the peak SAR values for the upper ear at a depth of 3-5 cm from the side of the head against which the phone is held, and are relatively miniscule elsewhere.

We have verified the highlights of the numerical calculations by means of a head-shaped experimental model made of tissue-equivalent materials simulating the electromagnetic properties (dielectric constant and electrical conductivity) of skull, brain, muscle, eyes, and ears developed for use at the cellular telephone frequency of 835 MHz. For this heterogeneous model, the SARs were obtained experimentally by measuring the radio frequency electric fields that were created by each of the telephones.

Based on the detailed studies of these telephones involving both shorter and longer antennas, the highlights of the results are as follows:

1. For a maximum possible antenna power of 600 mW, the power absorbed by the head and neck, depending on the telephone and the nature of its antenna, can vary from 41 to 136 mW. The power absorbed by the whole body is not much higher and can vary from 57 to 168 mW.

2. The peak SAR averaged over any 1 g of tissue defined as a volume in the shape of a cube occurs for the volume involving the upper ear. The peak 1 g SAR is on the order of 0.26 to 0.69 W/kg, depending on the telephone and the nature of its antenna. This is considerably smaller than the 1.6 W/kg suggested in the ANSI/IEEE C95.1-1992 safety guidelines. If the 1 g of tissue in the form of a cube is all taken to be the inside tissue such as for the brain, the peak 1 g SAR is even smaller. For the various telephones we have found the peak values of the SARs for any 1 g of tissue, all in the brain, to be between 0.06 to 0.41 W/kg.

3. The whole-body-average SAR can be obtained by dividing the total power absorbed by the weight of the body. For total-body absorbed powers on the order of 57 to 168 mW, a whole-body-average SAR on the order of 0.8 to 2.35 mW/kg is obtained. Once again, this is a factor of 34 to 100 times smaller than the whole-body-average SAR of 0.08 W/kg or 80 mW/kg considered to be acceptable by the ANSI-1992 safety standard.

Another factor to be considered is the averaging time of 30 minutes prescribed in the ANSI safety guideline at the cellular telephone frequency of 820-850 MHz. The time-averaged values of the whole-body-average and spatial-peak SARs would, therefore, be smaller than the above quoted values if the cellular telephone is in operation for only a fraction of time in any given 30-minute period.